The effects of climate change on infectious diseases with cutaneous manifestations

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TITLE: The effects of climate change on infectious diseases with cutaneous manifestations

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Abstract

Background: Anthropogenic climate change affects the burden of infectious diseases via several interconnected mechanisms. In recent years, there has been greater awareness of the ways in which climate-sensitive infectious diseases pose a growing threat to global public health.

Objective: To categorize and describe the effects of climate change on infectious diseases with skin manifestations.

Methods: A scoping review of the MEDLINE and PubMed online databases for climate-sensitive infections was performed in February and March 2020. A representative selection of conditions with skin manifestations was included in this review.

Results: Several representative climate-sensitive infectious diseases were identified in each of the following categories: (1) vector-borne infectious diseases, (2) infectious diseases associated with extreme weather events, and (3) infectious diseases linked to human migration.

Conclusions: Climate variables directly influence the survival and reproduction of infectious microorganisms, their vectors, and their animal reservoirs. Due to sustained warmer temperatures at higher latitudes, climate change has expanded the geographic range of certain pathogenic microbes. More frequent climate change-related extreme weather events create circumstances where existing infectious microorganisms flourish and novel infections emerge. Climate instability is linked to increased human migration, which disrupts healthcare
infrastructure as well as the habitats of microbes, vectors, and animal reservoirs, and also leads
to widespread poverty and overcrowding. Dermatologists should understand that climate
change will affect the burden and geographic distribution of infectious diseases, many of which
have cutaneous signs and might be encountered in their regular practice.

Keywords: vector-borne, dermatology, skin, temperature, extreme weather events, migration

Abbreviations: World Health Organization (WHO); extreme weather events (EWE); vector-
borne diseases (VBD); West Nile virus (WNV); Hand Foot and Mouth Disease (HFMD); Rocky
Mountain Spotted Fever (RMSF); Chagas Disease (CD)

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Highlights:
- Global warming expands the range of microorganisms, vectors, and animal reservoirs
- The current vectorial capacity of *Aedes* mosquitoes is at a record high and rising
- Extreme weather events increase the risk for certain infections with skin findings
- Coccidioidomycosis and *Vibrio* infections are occurring at higher latitudes
- Mass migration due to regional climate instability poses public health threats
Introduction

According to the World Health Organization (WHO), the most significant effects of climate change on human health will be driven by infectious diseases and undernutrition. (Hales et al. 2014) Climate variables affect all components of every ecosystem (Table 1). In the biomedical paradigm, this includes all microorganisms (beneficial and pathogenic; opportunistic and indifferent) that are involved in human health and affairs. The geographic expansion of microbes and vectors into new territories, made possible by sustained warmer temperatures at higher latitudes and increased human travel, exposes all planetary life to diseases previously unknown in particular habitats. More frequent extreme weather events (EWEs), (National Climate Assessment) including heat waves, drought, floods, (Table 2), create circumstances where existing infectious microorganisms flourish and novel infections emerge. Furthermore, in many regions, the myriad consequences of climate change drive mass intranational and international human migration, which disturbs regional healthcare infrastructure and the habitats of microbes, vectors, and animal reservoirs.

Climate-sensitive infections have various transmission patterns (Table 3), including vector-borne, water-borne without requiring vectors, and human-to-human. Physicians who trained or practice where these diseases are rare may find them challenging to recognize and diagnose. Herein, we review the effects of climate change on infectious diseases with dermatologic manifestations.

Climate-sensitive Vector Borne Diseases
Vector-borne diseases (VBDs) are infectious diseases transmitted by living organisms, most commonly blood-sucking arthropods such as mosquitoes, ticks, flies, and fleas (Table 4). (Caminade et al. 2016) Globally, VBDs cause >700,000 deaths annually, (World Health Organization 2020) and many lack vaccines, disease-specific treatments, or both. Over the last 150 years, major advances in public health – including sanitation, water supply safety, vector control, and vaccination – drove a steady decline in the burden of VBDs. The overall prevalence of major, potentially life-threatening VBDs continued to decline from 2005-2015, (Wang et al. 2016b) likely due to improved healthcare infrastructure and declining severe poverty worldwide. However, climate change threatens these gains, and in some cases, may reverse disease-specific trends.

Climate variables affect the environmental suitability for VBD transmission in many ways. Warming promotes expansion of geographic ranges of vector and reservoir populations, which establish themselves at higher latitudes and altitudes, or across more seasons (i.e., during winter months when infections were previously rare). This is apparent in increasing numbers of reported VBDs from arctic/subarctic regions, where warming is progressing more quickly and to a greater degree compared to lower latitudes. (Waits et al. 2018) Warmer temperatures often shorten pathogen development time in vectors and quicken vector life cycles, (Greer et al. 2008) such that pathogen and vector populations may enter logarithmic growth. Changes in rainfall, including more frequent flooding, directly affect vectorial capacity (the efficiency with which vectors become infected with, carry, and transmit pathogens). Finally, environmental
degradation – either manmade or due to EWEs – disrupts the habitats of disease vectors and animal reservoirs.

*Mosquito-borne illnesses*

**Dengue**

Dengue is a VBD caused by the dengue virus, a flavivirus transmitted to humans by *Aedes aegypti* and *Aedes albopictus* mosquitoes. As of 2019, approximately 3-billion people live in areas at-risk for dengue, and an estimated 400-million dengue cases occur annually. (Wilder-Smith et al. 2019b) Only 25% of infected persons develop symptoms – typically a mild, self-limited febrile illness. (Wilder-Smith et al. 2019b) Facial flushing and blanching macular erythema with islands of sparing (*Figure 1*), may appear during the acute phase. (Wilder-Smith et al. 2019b) Rarely, severe and potentially fatal complications, including multisystem vascular leak syndrome and hemorrhagic disease, develop. (Wilder-Smith et al. 2019b) Persons previously infected with a different dengue serotype, children, and pregnant women, especially during the third trimester, have higher risk for severe disease. (Wilder-Smith et al. 2019b)

No disease-specific treatments for dengue are available. The first dengue vaccine, CYD-TDV (*Dengvaxia*, SanofiPasteur), is a recombinant, live-attenuated tetravalent vaccine approved by the United States (US) Food and Drug Administration in 2019. (United States Food and Drug Administration 2019) Its efficacy is influenced by viral serotype and host baseline serostatus. Seronegative individuals who receive the vaccine are more likely to develop severe disease with subsequent natural dengue infections. (Hadinegoro et al. 2015) The WHO now recommends
incorporating antibody screening into vaccine campaigns, so that only seropositive individuals are vaccinated. (Wilder-Smith et al. 2019a)

While the incidence and mortality of other VBDs has declined recently, dengue-related mortality increased nearly 50% from 2005-2015. (Wang et al. 2016a) Moreover, in the past half-century, dengue’s worldwide incidence rose 30-fold. (Caminade et al. 2016) Approximately 75% of the global disease burden is in Asia; (Wilder-Smith et al. 2019b) Southeast Asia experienced the largest increase in recent dengue-related mortality. (Watts et al. 2019) Indeed, dengue is now the leading cause of fever in travelers returning from Southeast Asia, surpassing malaria. (Schwartz et al. 2008) These trends reflect a steady worldwide increase in vectorial capacity for both dengue vectors, (Watts et al. 2019) which peaks near 29°C. (Liu-Helmersson et al. 2014) Traditionally confined to the tropics, dengue’s geographic range is spreading because of warmer temperatures and increased human movement worldwide. (Liu-Helmersson et al. 2014) Since 2010, sporadic autochthonous transmission has been reported in new regions, including Croatia, (Gjenero-Margan et al. 2011) southern France, (La Ruche et al. 2010) Portugal, (Wilder-Smith et al. 2014) and the southern US (Florida, Texas, North Carolina). (Centers for Disease Control and Prevention: National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) - Division of Vector-Borne Diseases 2020) Currently, approximately 30 US states are in the “likely” or “very likely” range of both mosquito vectors. (Centers for Disease Control and Prevention 2017) During this century, continued globalization and increasingly hospitable environments for *Aedes* spp. (due to global warming, forest destruction, disturbed urban and peri-urban environments, human influence on land-use
patterns, etc.) are projected to enable dengue’s geographic range to continue expanding. (Liu-Helmersson et al. 2014) As the distribution of each serotype expands, more people are at risk for developing subsequent dengue infections, which are usually more severe; thus, the global burden of disease may increase substantially.

Chikungunya

The chikungunya virus, a togavirus, is also transmitted by Aedes. (Morens and Fauci 2014) Most infected patients (72-95%) develop acute-phase symptoms, (Staples et al. 2009) which include fever, severe symmetric polyarthralgias (typically fingers, wrists, elbows, knees, ankles), (Staples et al. 2009) and a morbilliform exanthem. (Morens and Fauci 2014) Despite low mortality, chikungunya has substantial acute and chronic morbidity; 48% of persons develop post-chikungunya chronic inflammatory rheumatism, typically 20 months later. (Yactayo et al. 2016) This causes economic losses, directly from healthcare costs and indirectly from impaired productivity. (Yactayo et al. 2016) Currently, there is no preventive vaccine or disease-specific treatment for chikungunya.

Chikungunya outbreaks are climate sensitive. They occur mainly in rainy seasons, when mosquito density is maximal, and are rare at altitudes >2300m. (Yactayo et al. 2016) The first modern outbreak of chikungunya occurred in Tanzania (then Tanganyika) in the late 1950s. Since then, globalization has facilitated viral spread. In 2007, a single infected traveler arriving from South Asia led to a 200-person outbreak in Italy. (Angelini et al. 2007) The first endemic cases in the Caribbean occurred in December 2013. (Morens and Fauci 2014) Since then,
multiple cases occur annually in the US, mostly in returning travelers, except for occasional autochthonous cases in Florida and Texas. (Centers for Disease Control and Prevention 2019a) Global spread is partly due to an adaptive viral mutation that improved its transmissibility by A. albopictus, which survives at cooler temperatures than A. aegypti. (Weaver 2014)

**Zika**

Zika virus is another flavivirus transmitted by Aedes mosquitoes. Approximately 20% of infected persons become symptomatic. (Nawas et al. 2016) Infection resembles mild dengue and may include fevers, rash, arthritis/arthralgia, and conjunctivitis; (Nawas et al. 2016) conjunctivitis (scleral erythema) may be more prominent with Zika than with other flavivirus infections. (Koh et al. 2019) Dermatologic manifestations include a morbilliform exanthem, erythematous acral macules and papules, and post-illness palmar desquamation. (Nawas et al. 2016) Zika first reached the Americas (Brazil) in 2015, (Mayer et al. 2017) and was soon implicated as causing devastating neurological effects, including agyria and microcephaly, in utero. The WHO declared a public health emergency of international concern. Zika virus transmission occurs at 22.7-34.7°C, and is maximal at 29°C. (Tesla et al. 2018) Worldwide, as more regions approach this temperature and more immunologically naïve persons are exposed, additional outbreaks will likely occur.

**West Nile Virus**

West Nile Virus (WNV) is a flavivirus maintained in a bird-mosquito transmission cycle and has been identified in >65 mosquito species and >300 bird species in the US alone. (Petersen et al.
However, only a few *Culex* species are competent at transmitting the virus to humans, who are typically dead-end viral hosts. (Petersen et al. 2013) Clinical manifestations include an uncommon morbilliform rash, typically on days 5-12 of illness, affecting the torso and extremities, sparing palms and soles. (Ferguson et al. 2005; Tilley et al. 2007) No vaccines or disease-specific treatments are available.

WNV was introduced into the western hemisphere (New York) in 1999, spread to the Pacific Coast by 2003, then to South America by 2005. (Petersen et al. 2013) WNV transmission is enhanced in warmer temperatures, which shorten incubation time within mosquitoes and increase efficiency of transmission to birds. (Reisen et al. 2006; Kilpatrick et al. 2008) Outbreaks in Canada, (Giordano et al. 2017) Israel, (Paz 2006) and Russia (Platonov et al. 2008) correlate with periods of high temperatures. In the US, cases peak in late summer. (ArboNET - Arboviral Diseases Branch: Centers for Disease Control and Prevention 2019b) US cases peaked at 9,862 in 2003, but approximately 2,000 cases still occur annually. (ArboNET - Arboviral Diseases Branch: Centers for Disease Control and Prevention 2019a)

**Sandfly-Borne Illnesses**

**Leishmaniasis**

The term, leishmaniasis, encompasses a variety of acute and chronic infections caused by several protozoa in the genus *Leishmania* and transmitted by phlebotomine sandflies. Cutaneous leishmaniasis is the most common form of disease worldwide, but visceral disease,
mainly found in the Old World, is the most virulent type. Cutaneous diseases manifests with non-healing ulcers, usually on exposed surfaces of head, neck, forearms, and hands. (Figure 2)

Temperature and humidity influence sandfly survival and reproduction. (Negev et al. 2015) In the last several decades, rates of autochthonous cutaneous leishmaniasis in new areas have risen as environmental conditions become more favorable. In southern Europe, leishmaniasis case numbers are rising as the sandfly’s geographic range expands northward. (Maroli et al. 2008) In one series of cases diagnosed in Texas from 2007-2017, 59% of cutaneous leishmaniasis cases occurred in patients with no travel outside the US in the prior decade, representing a shift away from mostly travel-related leishmaniasis in the US. (McIlwee et al. 2018)

Tick-Borne Illnesses

Lyme Disease

Lyme disease is a bacterial infection caused by several spirochetes, mainly *Borrelia burgdorferi* and *Borrelia azfeli*. (Stanek et al. 2012) It is transmitted only by *Ixodes* ticks: *Ixodes scapularis* in eastern/central North America, *Ixodes pacificus* along North America’s West Coast, and *Ixodes ricinus* in Europe. (Stanek et al. 2012) Important animal reservoirs include small mammals (e.g., mice, voles) and birds. Whitetail deer, which can support huge numbers of ticks, have an important role in maintaining tick populations. (Stanek et al. 2012) Lyme disease manifests in three clinical stages, all with cutaneous manifestations, including localized erythema migrans (stage 1) (Figure 3a-b), disseminated erythema migrans (stage 2) (Figure 3c), and acrodermatitis
chronica atrophicans and borrelial lymphocytoma (stage 3; both phenomena are unique to Europe). (Stanek et al. 2012)

Lyme disease occurs at temperate latitudes and only in the Northern Hemisphere. Disease risk has been linked to warm winters, high summer temperatures, and relatively low interseasonal temperature variation. (Estrada-Peña et al. 2011) The overall Lyme disease case count is rising; moreover, its geographic range is expanding northward in both North America and Europe, (Jaenson et al. 2012) and will likely continue doing so due to the consequences of climate change on tick and reservoir populations. (Roy-Dufresne et al. 2013; Simon et al. 2014)

**Rocky Mountain Spotted Fever**

Rocky Mountain Spotted Fever (RMSF) is a life-threatening condition caused by *Rickettsia rickettsii*, transmitted by American dog ticks (*Dermacentor variabilis*) and Rocky Mountain wood ticks (*Dermacentor andersoni*). Recently, an unrelated tick, the brown dog tick (*Rhipicephalus sanguineus*), was confirmed as a vector in eastern Arizona, discontinuous with areas of *Dermacentor*-borne RMSF. (Demma et al. 2005; Traeger et al. 2015; Nawas et al. 2016)

Clinical manifestations include flu-like symptoms with high fever, severe headache, malaise, and an acral, macular, erythematous rash that becomes petechial. (Nawas et al. 2016) Early recognition is essential, because diagnostic and treatment delays are associated with high mortality. (Nawas et al. 2016)
The incidence of RMSF has risen steadily over the past 20 years. (Centers for Disease Control and Prevention: National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) - Division of Vector-Borne Diseases 2019) While disease reporting practices and improved physician awareness are contributing factors, (Openshaw et al. 2010) climate change may also have a role. Incidence is influenced by humidity and temperature, which affect the ranges of ticks and reservoirs and the amount of skin humans expose. (Raghavan et al. 2016) RMSF has its highest incidence in June and July, when adult *Dermacentor* are most active. (Centers for Disease Control and Prevention: National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) - Division of Vector-Borne Diseases 2019) Transmission via *R. sanguineus* also increases at warmer temperatures. (Parola et al. 2008)

The geographic range of RMSF is expanding in latitude and altitude. (Raghavan et al. 2016) Given the severity of untreated RMSF, dermatologists should be aware that it may appear in previously nonendemic areas.

*Chagas disease*

Chagas disease (CD) is caused by the protozoan *Trypanosoma cruzi*, transmitted to humans through bites of triatomine insects (*Triatoma, Panstrongylus, Rhodnius*). (Pérez-Molina and Molina 2018) Acute phase symptoms include fever, inoculation site inflammation, unilateral eyelid edema (Romaña sign), lymphadenopathy, and hepatosplenomegaly. This phase lasts 4-8 weeks and resolves spontaneously. Approximately 30-40% later develop visceral involvement, which can cause substantial morbidity and death. (Pérez-Molina and Molina 2018)
Triatomids are climate-sensitive insects. To avoid dehydration, they feed more often during times of high temperature (>30°C) and low humidity. Higher temperatures are associated with shorter life cycles (Carcavallo and Casas 1996) and faster parasite maturation (Asin and Catala 1995).

Historically, CD has been endemic to rural Latin America, where poor housing conditions favor vector infestation. Most persons diagnosed in the US acquired their infections in Latin America (Montgomery et al. 2016). However, CD’s geographic range may be expanding; in the US, 28 autochthonous cases were reported from 1955-2015, but >75% of these were after 2011 (Bern et al. 2011; Montgomery et al. 2016). Since 2015, several additional autochthonous US cases were reported (Hernandez et al. 2016; Gunter et al. 2017; Harris et al. 2017; Webber et al. 2017; Beatty et al. 2018; Turabelidze et al. 2020). In the US, local transmission is typically sylvatic (related to outdoor exposures) rather than domestic (from infested human dwellings) (Turabelidze et al. 2020). Models of future distribution predict further poleward expansion (Garza et al. 2014).

**Climate-Sensitive Infectious Diseases and Extreme Weather Events**

Many microorganisms have distinct geographic distributions based on the ecological niches of microbes, vectors, nonhuman reservoirs, and human populations. Climate and weather patterns, generally, and temperature patterns, specifically, are among the most important ecological variables that define distributions across latitude and altitude. Human populations
living outside the historical thermal boundaries of particular microbes may not have been exposed to these organisms. Changes in global temperature patterns therefore expose new and vulnerable populations to unfamiliar infectious diseases.

Moreover, infectious outbreaks often cluster around EWEs, which are increasingly common because of climate change. For example, drought-associated water scarcity impairs personal and public sanitation and may lead to contaminated water exposure. Conversely, severe flooding damages infrastructure, which can compromise water supply safety, and expose humans to water-borne pathogens. (Bandino et al. 2015; McMichael 2015) Several outbreaks of infectious diseases, including hantavirus infection (Four Corners region of the southwestern US) in the early 1990s, (Wenzel 1994) cryptosporidiosis (Milwaukee, Wisconsin, 1993) (Mac Kenzie et al. 1994), and malaria (East Africa) (Loevinsohn 1994; Brown et al. 1998; Kilian et al. 1999; Lindsay et al. 2000) occurred after severe flooding. Given the skin barrier’s protective role, skin disease is especially common after flooding. (Shabir 2013) Below, we review specific EWE-associated infections with cutaneous manifestations.

Coccidioidomycosis

Coccidioidomycosis, or Valley Fever, is a systemic mycosis caused by the dimorphic organisms, *Coccidioides immitis* and *Coccidioides posadasii*, which are endemic to arid regions of the Americas. Their confined geographic range reflects climate sensitivity. Their spores, found in soil approximately 10cm sub-surface, require moist periods to germinate, followed by dry spells to aerosolize. (Nguyen et al. 2013; Matlock et al. 2019) Precipitation and wind are primary
contributors to aerosolization. During heat waves, high temperatures deplete soil biota, reducing competition against *Coccidioides*. (Maddy 1957, 1965) Up to 50% of people living in endemic areas have been exposed to some form of *Coccidioides*, mainly via spore inhalation (rarely via cutaneous inoculation), but most never display symptoms. (Matlock et al. 2019) Approximately 40% of infected people become symptomatic, and only 1% develop disseminated disease. (Sondermeyer et al. 2016) Transplant recipients, certain ethnic groups (e.g., Filipino-Americans), and patients with diabetes, malignancy, and HIV experience higher mortality. (Sondermeyer et al. 2016)

In the last two decades, the incidence of coccidioidomycosis has risen steadily for several reasons. Better diagnostic tests improve case detection and regional population growth increases the size of vulnerable populations. Climate change leads to edaphic (soil-related) changes that permit marked expansion of the fungus’s geographic range. (Centers for Disease Control and Prevention 2019b) Spores have now been identified far north of the warm, arid Southwest, including Oregon. (Hawryluk 2016) Since 2010, at least 16 autochthonous cases have occurred in south-central Washington State. (Washington State Department of Health 2020) Heavy rainfall in 2016 after prolonged drought in California was associated with increased cutaneous coccidioidomycosis incidence. (Coates and Fox 2018; Shiu et al. 2018) More recently, California’s wildfires have been linked to increased risk for coccidioidomycosis. (Mulliken et al. 2019)

Vibrio species
*Vibrio vulnificus* is a gram-negative bacteria transmitted via exposure to marine and brackish waters. (Park and Lee 2018) Typical clinical manifestations include bullous hemorrhagic cellulitis of distal extremities. (Park and Lee 2018) Risk for cutaneous *Vibrio* infections increases after coastal flooding, as seen after Hurricane Katrina (2005). (Centers for Disease Control and Prevention) The worldwide environmental suitability for all pathogenic *Vibrio* species has steadily increased for several decades, particularly in northern regions (Watts et al. 2019) and cases are now being seen along the Northern European coastline. (Vezzulli et al. 2013; Huehn et al. 2014; Baker-Austin et al. 2017)

**Hand, Foot, and Mouth Disease**

Hand, Foot, and Mouth Disease (HFMD) is caused by various human enteroviruses. The condition typically affects children <5-years-old, manifesting with erythematous papules and vesicles distributed acrally and intraorally (Figure 4a-c). Rarely, severe systemic manifestations occur. Onychomadesis may develop (Figure 4d). Enteroviruses are sensitive to temperature and humidity. (Coates et al. 2019) Climate change may have a role in HFMD epidemiology. In the past 30 years, HFMD has become a substantial public health burden in southeast Asia, where large, frequent, and virulent outbreaks have killed thousands of children. (Coates et al. 2019)

**Future climate-sensitive microorganisms**

In addition, higher temperatures pose the threat that new, previously unidentified infectious diseases will emerge as a consequence of progressive microbe adaptation. For example, most fungal species fare poorly at human core temperatures, which are far above average ambient...
temperatures anywhere in the world. However, many fungi have the capacity to develop thermostolerance, (de Crecy et al. 2009; Casadevall et al. 2019) which may eventually enable them to defeat the human “endothermy thermal barrier.” (Casadevall and Casadevall 2020) Likewise, viruses that currently pose no threat to humans might spillover to humans if they acquire the capacity for replication at higher temperatures. Additionally, organisms (including those that cause tularemia and anthrax) that have been frozen in thawing arctic permafrost may emerge to cause a greater disease burden. (Waits et al. 2018)

Human Migration and Infectious Disease

For millennia, humans have migrated for environmental, sociopolitical, and economic reasons. Climate change threatens already-marginalized populations worldwide, especially in regions dependent on subsistence agriculture. Crop production is threatened by pests, pathogens, and EWEs. Globally, crop yields for staple products (e.g., maize, winter wheat, soybeans) have declined in concert with rising temperatures. (Watts et al. 2019) Further, the number of undernourished persons worldwide has been increasing since 2014 due to impaired access to and affordability of food. (Watts et al. 2019) Undernutrition predisposes to numerous infectious diseases. (The Lancet Infectious Diseases 2017)

When local environments are no longer salubrious, populations decline and humans migrate, often across international borders when home countries become inhospitable. Mass migration destabilizes healthcare infrastructure, weakening individual-based medical care and public health measures. This decreases access to healthcare, lowers vaccination rates, impairs food

18
quality and quantity, limits clean water access, degrades hygiene, and leads to overcrowding. This further exposes migrants to communicable diseases associated with poverty, including tuberculosis, ectoparasite (scabies and lice) infestations, HIV infection, and diarrheal diseases – many of which have dermatologic manifestations. Disease vectors and animal reservoirs are also affected – increased cases of cutaneous leishmaniasis have been linked to conflict and mass human migration in the Middle East. (Eroglu and Ozgoztasi 2019; Muhjazi et al. 2019)

Conclusion

Climate change alters the epidemiology of infectious diseases. VBDs may emerge or re-emerge within populations when climate variables change significantly. Climate-change has driven increased environmental suitability for infectious diseases – from changes in climate, soils, forest cover, and land use. The current COVID-19 pandemic illustrates the consequences of failing to respond to an infectious disease outbreak swiftly and in a manner based on expert recommendations for containing disease spread. As the climate crisis unfolds, humanity will likely be challenged by additional opportunities to respond to novel or emerging infectious diseases. This warrants a concerted effort to develop enhanced surveillance methods to detect emerging and re-emerging infectious diseases, particularly those with no disease-specific vaccinations or treatments. Climate-based warning systems that identify regions at particular risk for disease outbreaks are in development. Targeted vector-control efforts, which have successfully addressed certain arbovirus outbreaks in the past, may be used successfully in areas with emerging diseases. Given concern for antibiotic resistance and waning supplies of next-generation antibiotics, good stewardship of existing antibiotics and continued research to
develop new antibiotics is essential. Dermatologists should understand that climate change will affect the burden and geographic distribution of infectious diseases, many of which have cutaneous signs and might be encountered in their regular practice.
REFERENCES


Caminade C, McIntyre MK, Jones AE. Climate change and vector-borne diseases: where are we next heading? J Infect Dis. 2016;214(9):1300–1.


Eroglu F, Ozgoztasi O. The increase in neglected cutaneous leishmaniasis in Gaziantep province of Turkey after mass human migration. Acta Trop. 2019;Apr(192):138–43.


Jaenson TGT, Hjertqvist M, Bergström T, Lundkvist Å. Why is tick-borne encephalitis increasing? A review of the key factors causing the increasing incidence of human TBE in Sweden.


Platonov AE, Fedorova M V., Karan LS, Shopenskaya TA, Platonova O V., Zhuravlev VI.


United States Food and Drug Administration. Approval Letter - Dengvaxia [Internet]. Silver Spring, MD; 2019. Available from: https://www.fda.gov/media/124402/download


Weaver SC. Arrival of chikungunya virus in the New World: prospects for spread and impact on


**Figure 1. Dengue.** Morbilliform eruption with islands of sparing due to acute Dengue.

**Figure 2. Cutaneous Leishmaniasis.** Classic “Chiclero’s ulcer” on the ear, caused by *Leishmania mexicana.*
**Figure 3. Lyme disease.** Clinical stages of Lyme disease: A-B. Localized erythema migrans (stage 1), which may lack the classic “bullseye” appearance; C. Multiple red patches of disseminated Lyme disease, also called secondary erythema migrans (stage 2).

**Figure 4. Hand, Foot, and Mouth Disease (HFMD).** A. Classic acral papules and vesicles in a patient with HFMD; B. Papules and vesicles overlying the knee in a patient with HFMD; C. Diffuse eczema coxsackium; D. Onychomadesis following HFMD.

**Table 1 – Essential climate variables**

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<td>• Latent and sensible heat fluxes</td>
</tr>
<tr>
<td><em>Upper atmosphere</em></td>
<td><em>Biogeochemistry</em></td>
<td>• Leaf area index (LAI)</td>
</tr>
<tr>
<td>• Earth radiation</td>
<td>• Inorganic carbon</td>
<td>• Permafrost</td>
</tr>
<tr>
<td>budget</td>
<td>• Nitrous oxide</td>
<td>• River discharge</td>
</tr>
<tr>
<td>• Lightning</td>
<td>• Nutrients</td>
<td>• Snow</td>
</tr>
<tr>
<td>• Temperature</td>
<td>• Ocean color</td>
<td>• Soil carbon</td>
</tr>
<tr>
<td>• Water vapor</td>
<td>• Oxygen</td>
<td>• Soil moisture</td>
</tr>
<tr>
<td>• Wind speed /</td>
<td>• Transient tracers</td>
<td></td>
</tr>
<tr>
<td>direction</td>
<td></td>
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</tr>
</tbody>
</table>
Table 2 – Extreme weather events

<table>
<thead>
<tr>
<th>Extreme Weather Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Waves</td>
</tr>
<tr>
<td>Drought</td>
</tr>
<tr>
<td>Heavy downpours</td>
</tr>
<tr>
<td>Floods</td>
</tr>
<tr>
<td>Hurricanes</td>
</tr>
<tr>
<td>Winter storms</td>
</tr>
</tbody>
</table>

Table 3 – Climate-sensitive infectious diseases with dermatologic manifestations

<table>
<thead>
<tr>
<th>Mechanism of climate sensitivity</th>
<th>Specific disease examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infectious microbes are directly sensitive to climate variables (temperature, rainfall, humidity)</td>
<td><strong>Viruses:</strong> Enteroviruses (Hand, Foot, and Mouth Disease), Chikungunya, Zika</td>
</tr>
<tr>
<td></td>
<td><strong>Bacteria:</strong> <em>Vibrio vulnificus</em> infection</td>
</tr>
<tr>
<td></td>
<td><strong>Fungi:</strong> coccidioidomycosis</td>
</tr>
</tbody>
</table>
Enhanced survival and expanded geographic range of climate-sensitive vectors and animal reservoirs

**Aedes** mosquito species: Chikungunya, Dengue, Yellow Fever, Zika, Lymphatic filariasis,

**Anopheles** mosquito species: Lymphatic filariasis

**Culex** mosquito species: West Nile fever, Lymphatic filariasis

**Phlebotamine sandflies**: Leishmaniasis variants

**Ixodid (hard) ticks**: Lyme disease and other borrelial infections, Rickettsial diseases (spotted fever, Q fever), Tularemia

**Triatome bugs**: Chagas disease (American trypanosomiasis)

Increased incidence during and after extreme weather events

**Flooding**: *Vibrio vulnificus* infection, *Mycobacterium marinum* infection, melioidosis (*Burkholderia pseudomallei* infection), leptospirosis, *Chromobacterium violaceum* infection, chromoblastomycosis, blastomycosis, mucormycosis, dermatophytosis, immersion foot syndromes (polymicrobial infection)

**Drought**: Coccidioidomycosis

Human migration, overcrowding, and poverty caused by climate-change-related extreme weather events

Scabies infestation, body lice infestation (the vector for epidemic typhus and louse-borne/epidemic relapsing fever), tuberculosis, human immunodeficiency virus, diarrheal diseases

**Table 4** – Vector-borne diseases of human significance

<table>
<thead>
<tr>
<th>Vector</th>
<th>Disease caused</th>
<th>Type of pathogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosquitoes</td>
<td><strong>Aedes</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chikungunya</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Dengue</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Lymphatic filariasis</td>
<td>Parasite</td>
</tr>
<tr>
<td></td>
<td>Rift Valley Fever</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Yellow Fever</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Zika</td>
<td>Virus</td>
</tr>
<tr>
<td><strong>Anopheles</strong></td>
<td>Lymphatic filariasis</td>
<td>Parasite</td>
</tr>
<tr>
<td></td>
<td>Malaria</td>
<td>Parasite</td>
</tr>
<tr>
<td>Mosquitoes</td>
<td>Disease</td>
<td>Vector</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>--------</td>
</tr>
<tr>
<td><em>Culex</em></td>
<td>Japanese encephalitis</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Lymphatic filariasis</td>
<td>Parasite</td>
</tr>
<tr>
<td></td>
<td>West Nile fever</td>
<td>Virus</td>
</tr>
<tr>
<td>Aquatic snails</td>
<td>Schistosomiasis</td>
<td>Parasite</td>
</tr>
<tr>
<td>Blackflies</td>
<td>Onchocerciasis</td>
<td>Parasite</td>
</tr>
<tr>
<td>Fleas</td>
<td>Plague</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Tungiasis</td>
<td>Ectoparasite</td>
</tr>
<tr>
<td>Lice</td>
<td>Typhus</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Louse-borne relapsing fever</td>
<td>Bacteria</td>
</tr>
<tr>
<td>Sandflies</td>
<td>Leishmaniasis</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Sandfly fever</td>
<td>Virus</td>
</tr>
<tr>
<td>Ticks</td>
<td>Crimean-Congo hemorrhagic fever</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Lyme disease</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Relapsing fever (borreliosis)</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Rickettsial diseases (spotted fever, Q fever)</td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td>Tick-borne encephalitis</td>
<td>Virus</td>
</tr>
<tr>
<td></td>
<td>Tularemia</td>
<td>Bacteria</td>
</tr>
<tr>
<td>Triatome bugs</td>
<td>Chagas disease (American trypanosomiasis)</td>
<td>Parasite</td>
</tr>
<tr>
<td>Tsetse flies</td>
<td>Sleeping sickness (African trypanosomiasis)</td>
<td>Parasite</td>
</tr>
</tbody>
</table>

Adapted from: *The World Health Organization*: [https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases](https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases)